Science Questions → Goals → Approach → Parameter Requirements → Instrument Requirements

AEROSOLS-clouds-ecosystems (ACE)

The 'A' part of the mission

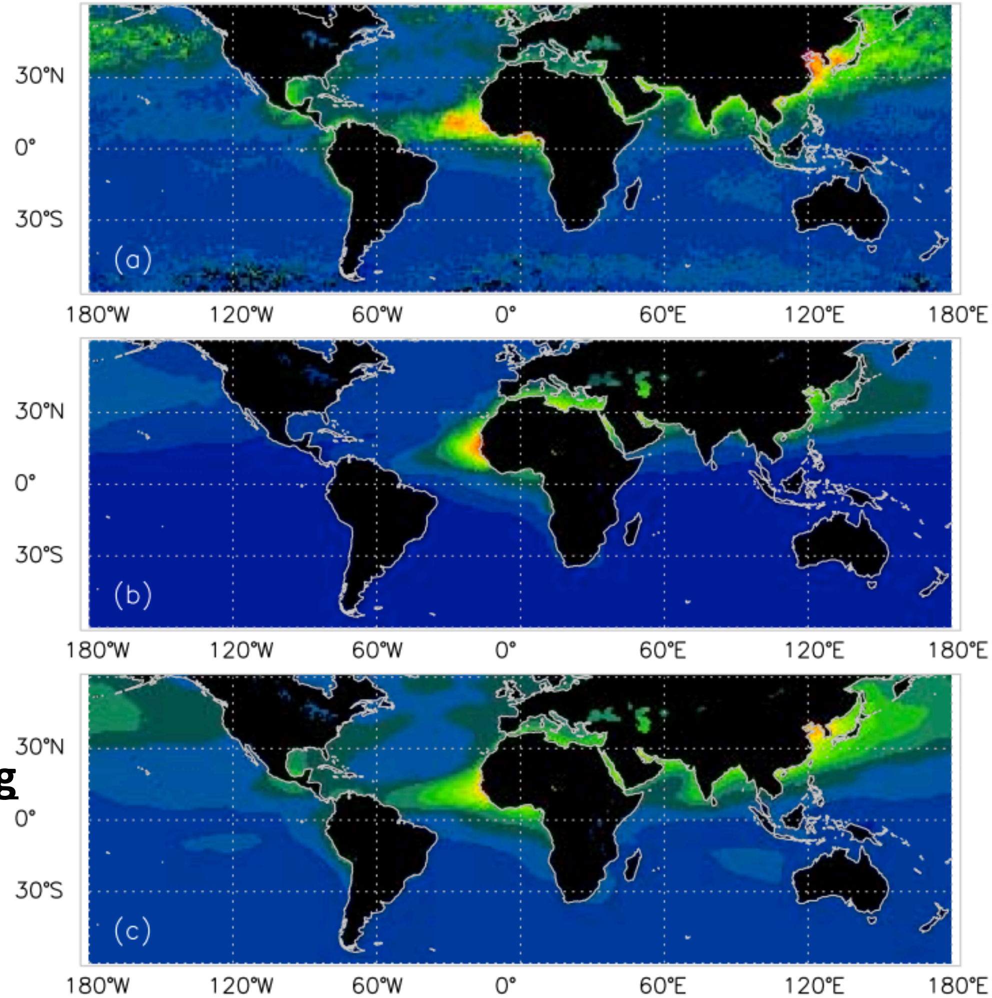
- The three scientific themes:
  1. Sources, processes, transport and sinks (SPTS)
  2. Direct aerosol radiative forcing and heating (DARF)
  3. Cloud-Aerosol Interaction (CAI)

SPTS

Three months of MODIS aerosol observations

Aerosol forecast model loading for same period

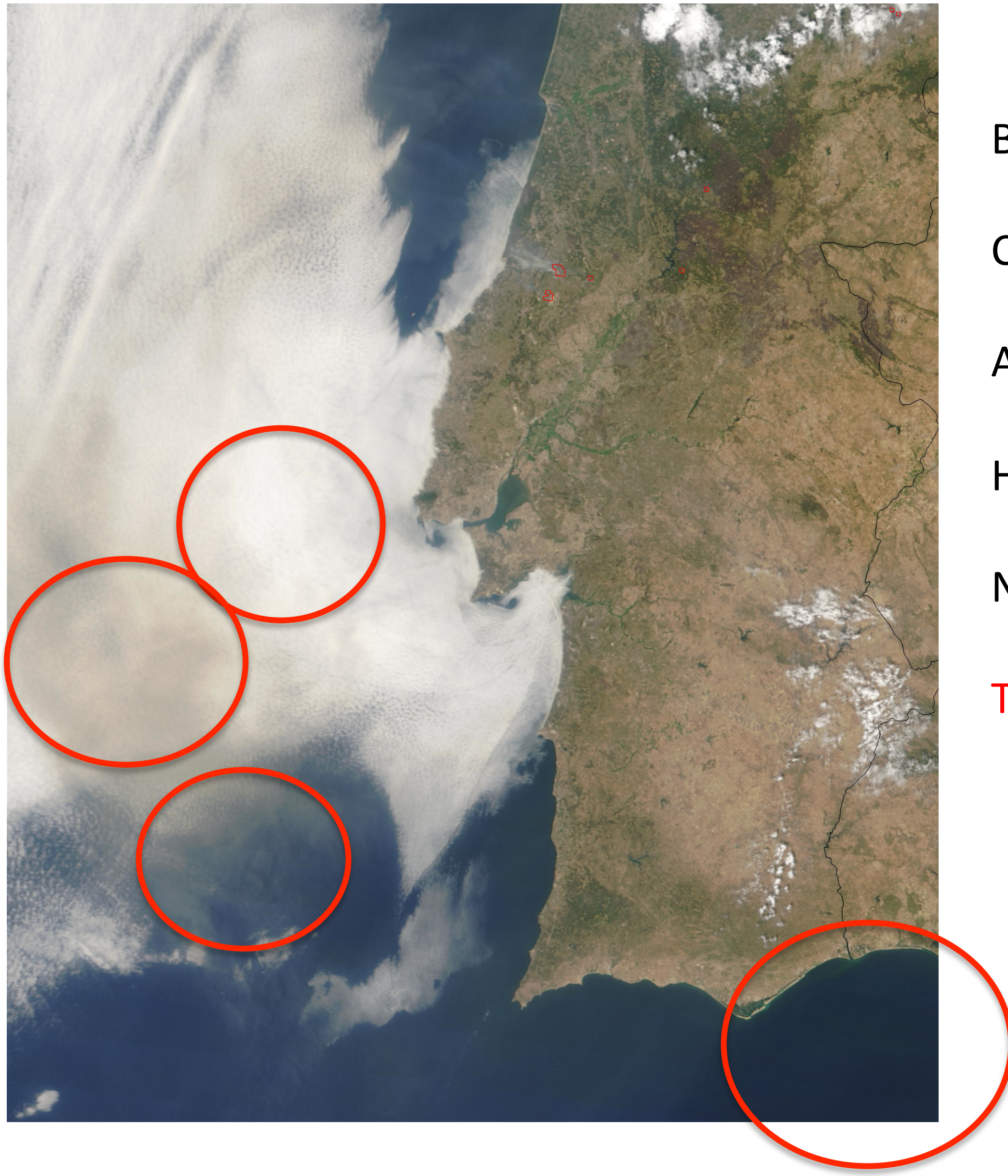
Aerosol forecast model **assimilating** satellite observations looks more like observations



- Satellite observations improve our modeling capabilities
- ACE observations will further improve models by providing more detailed information on aerosol **composition and vertical distribution**
- Improved models are key to (i) forecasts of extreme aerosol and weather event and (ii) predictions of aerosol impacts on climate

Zhang, Reid

DARF



MODIS day=220 year=2003; Portugal

Brightening or darkening?

Cooling or warming?

Above the cloud or below or inside?

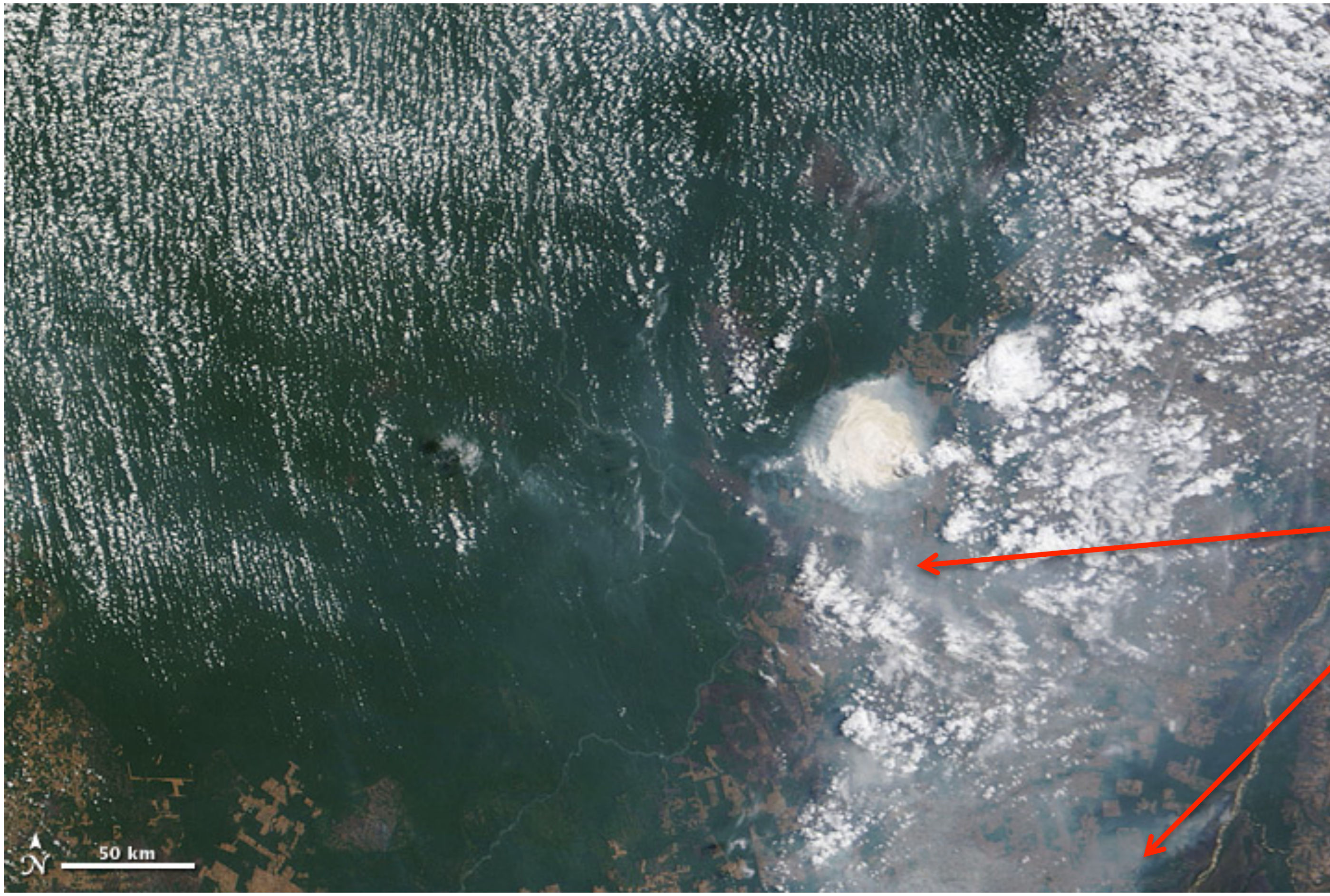
How dark (absorption properties)?

Natural or anthropogenic?

These questions cannot be answered today with the necessary accuracy or coverage.

We need a more quantitative characterization of the aerosol system.

CAI



aerosol

Inside the cloud or not?

Changes of clouds due to aerosols depend on particle number concentration

ACE will be able to derive this parameter for the first time

Science Questions → Goals → Approach → Parameter Requirements → Instrument Requirements

(1) What is the global and regional aerosol mass budget?
What is the mass flux into the global or regional atmosphere and out of the atmosphere, **partitioned by species**, and as a function of time?

(2) What is the impact of specific significant aerosol events such as wild fires, dust outbreaks, urban/industrial pollution, volcanic eruptions etc. on the local, regional and global aerosol burden?

SPTS

(3) What is the direct aerosol radiative forcing (DARF) at the top-of-atmosphere, within-atmosphere and at the surface?
Here, DARF is defined as the mean radiative flux perturbation due to the ***anthropogenic*** component of present-day aerosols (in units of Wm^{-2})

(4) What is the aerosol radiative heating of the atmosphere due to absorbing aerosols, and how will this heating affect cloud development and precipitation processes?

DARF

Science Questions → Goals → Approach → Parameter Requirements → Instrument Requirements

(5) How much do **anthropogenic additions to natural aerosol** affect the planetary energy balance via their influence on droplet and crystal nucleation?

(6) How does **the aerosol influence on clouds and precipitation via nucleation** depend on cloud updraft velocity and cloud type?

(7) How much does **solar absorption by anthropogenic aerosol** affect cloud radiative forcing and precipitation? (See DARF question #4).

(8) What are the key mechanisms by which clouds process **aerosols and influence the vertical profile of aerosol physical and optical properties**?

(9) What are the processes that cause a polluted non-precipitating airmass to rapidly change to a clean precipitating airmass?

CAI

Science Questions → Goals → Approach → Parameter Requirements → Instrument Requirements

Approach

- DARF, heating rates, mass budget, Cloud-Aerosol Interaction:
  Derive global tropospheric aerosol amounts and detailed characteristics

Sources: inverse methods, seasonal mapping, spatial classification

Injection height: lidar, stereo height, polarized spectral techniques

Transport fluxes: aerosol characterization + winds

Deposition: synthesis between models and measurements. Will require model development

- Combine **data from multiple sources including suborbital**
- Synthesize the observations with **modeling**

Science Questions → Goals → Approach → Parameter Requirements → Instrument Requirements

Satellite component will:

- quantify the optical depth of the aerosol,

- constrain particle composition as to chemical species,

- determine the forcing at the top and bottom of the atmosphere,

- quantify the amount of radiation absorbed in the atmospheric column, across a "broad" swath and

- determine the layer-resolved vertical distribution of the aerosol characteristics along a narrow swath or curtain

- determine injection heights

- locate, characterize and quantify point sources (fires/dust/powerplants)

Science Questions → Goals → Approach → Parameter Requirements → Instrument Requirements

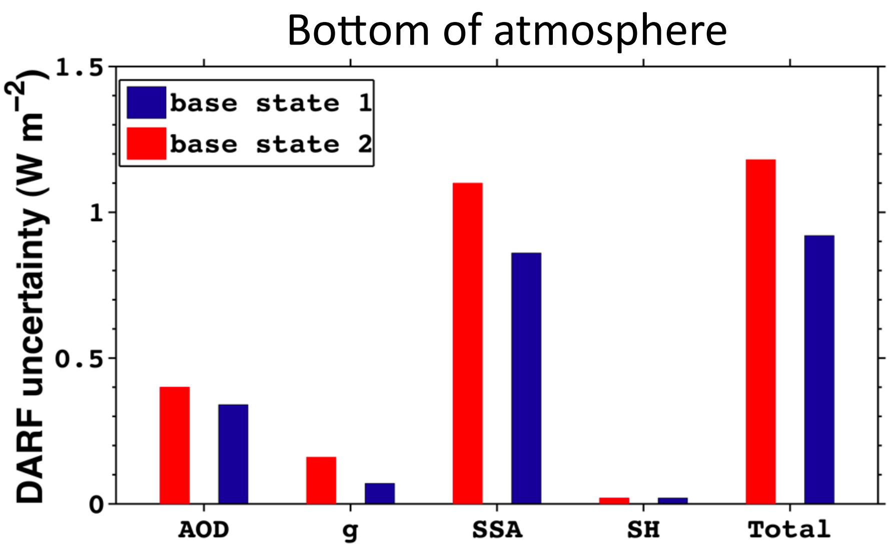
Required parameters and uncertainty

Column:	
$\tau_a(\lambda)$	±0.02 or 5%
- $\tau_{a\text{-}abs}(\lambda)$	±0.02*
- $m_a(\lambda)_{(2\ modes)}$	±0.02*
- $r_{eff,a}$ (2 modes)	±10%*
- $\nu_{eff,a}$ (2 modes)	±50%*
-morphology	*
$N_{a(2\ modes)}$	±100%*

Vertically resolved**:	
Extinction	± 0.025 km^{-1}*
$\omega_o(\lambda)$	±0.02*
$m_a(\lambda)$	±0.02*
-$r_{eff,a}$	±20%*
-morphology	*
$N_{a(2\ modes)}$	±100%*

*Denotes sufficient aerosol loading required and other restrictions
** 1.5 km layer in FT; 500 m layer in BL;
Vertically resolved necessary, mostly for SPTS-1, and DARF-4 questions
Column parameters necessary for all science questions.

Ambitious requirements based on Mishchenko et al (2004) and ACE-funded studies including: Loeb and Su (2010), Ackerman and Fridlind (submitted 2010) and unpublished ACE-supported work by Colarco, Sato etc.



DARF-3

Given the accuracy requirements on the previous page, what uncertainties are expected for observationally based DARF parameters?

ACE will provide first ever estimate of DARF **<u>at the surface</u>** to within 1 Wm^{-2} (tied to global evaporation rates and the hydrological cycle)

From ACE white paper. Modified version published in Loeb and Su (2010)

DARF-4

Daily averaged aerosol heating rate for INDOEX was
0.5^{o}K/day in a 1.5 km layer.

To provide useful information, ACE would need to have accuracy of half of that: 0.25^{o}K/day

To achieve 0.25 K/day SSA uncertainty:

± 0.02 when aerosol extinction is 0.17 km^{-1} (AOT=0.26 for Δz=1.5km)

± 0.05 when aerosol extinction is 0.07 km^{-1} (AOT=0.11 for Δz=1.5km)

To achieve 0.25 K/day AOT uncertainty for the vertical layer:

± 0.065 km^{-1} (ΔAOT=0.098 for Δz=1.5 km) when SSA = 0.95

± 0.025 km^{-1} (ΔAOT=0.038 for Δz=1.5 km) when SSA = 0.85

Based on a modeling study by Seiji Kato of a tropical atmosphere with a single layer layer cloud beneath a haze layer over ocean.
The aerosol is modeled as soot coated with water. The clouds are described as N=250 cm^{-3}; r_e=10 μm; LWC ~ 0.8 g/kg

(Seiji Kato)

Science Questions → Goals → Approach → Parameter Requirements → Instrument Requirements

Ace Mission:

Two instruments:

1. Imaging broad-spectral multi-angle polarimeter
2. $3\beta + 2\alpha + 2\delta$ HSRLidar

Aerosols will also make use of an ocean ecology spectrometer or other broad swath imager, but do not require it

Science Questions → Goals → Approach → Parameter Requirements → Instrument Requirements

Why the polarimeter?

- We are requiring retrieval of at least 11 aerosol parameters plus the surface in a column retrieval.

- Published sensitivity studies are not comprehensive but suggest:
  MODIS-like can retrieve 1 or 2 parameters (demonstrated)
  MISR-like can retrieve 3 or 4 parameters (demonstrated)
  Adding UV channels to MODIS could increase capability to 3 parameters
  APS or POLDER (polarization) can retrieve 10+ parameters

- But we require higher accuracy and spectral range, and perhaps a higher angular density than POLDER offers, broader spatial coverage than APS and finer spatial resolution than either

- Imaging is essential.
- 2-day global coverage for at least the intensity measurements (SPTS)
- 400 km swaths for the polarimetry (DARF)
- Aerosol requires 1 km polarimetric resolution; clouds require higher resolution for intensity
- Flying with the HSRL is fundamental

Science Questions → Goals → Approach → Parameter Requirements → Instrument Requirements

Why a $3\beta + 2\alpha + 2\delta$ HSR Lidar?

Three wavelengths for backscattering.
Two wavelengths for extinction.
Depolarization in 2 channels

$1\beta + 1\alpha$ allows for direct observations of extinction, not available now from CALIPSO (No more guessing a "lidar ratio" in the optical depth retrieval)

$2\beta + 1\alpha + 2\delta$ allows for <u>qualitative</u> vertical distribution of aerosol 'type'

$3\beta + 2\alpha + 2\delta$ provides <u>quantitative</u> information about aerosol optical and microphysical properties for aerosol absorption (heating rate) and concentration and size (for aerosol-cloud interactions)

Per current understanding, this is the minimum configuration necessary to retrieve vertical profiles of aerosol absorption for heating rates and other detailed aerosol properties.

Müller et al., (2001); Böckmann (2001)

A-Train + Terra + suborbital observations today

Allow us to constrain total aerosol "effect" at the top-of-atmosphere.
but NOT the anthropogenic "forcing"
and NOT at the Earth's surface

Allow us to identify aerosol "types" and their sources and transport
but NOT their physical and optical properties
and with large quantitative uncertainty

Provide vertical distribution of the aerosol
but NOT vertical distribution of aerosol-induced heating rates
or other detailed aerosol properties (size, shape, number concentration)

Provide a <u>proxy</u> for aerosol particle concentration
but NOT the number concentration itself
and with no information on vertical distribution

Provide a 10 year record of the aerosol system that begs for continuity and enhancement!

ACE will

- Allow us to quantify the aerosol budget:
  what and how much is being emitted, transported, breathed in,
  used as fertilization by biological systems and removed from the atmosphere;
  where does it come from and where does it go? (SPTS)

- Provide quantitative constraints on *anthropogenic* direct aerosol forcing
  at the top, bottom and within the atmosphere (DARF-3)

- Provide vertical distribution of detailed aerosol properties, including
  vertical profile of extinction, heating rates and number concentrations (DARF-4, CAI)

- Allow retrievals of aerosol particle number concentration so we don't
  have to guess anymore for cloud-aerosol interaction studies (CAI)

Suborbital measurements and interactive global modeling
are vital components of the ACE strategy

The ACE strategy is to provide the highest quality observational data for clouds and for aerosols, independently, then use each discipline's observations to tackle the difficult Cloud-Aerosol Interaction question.

Likewise we will provide high quality measurements for the ocean ecology community to use for atmospheric correction or for atmosphere-ocean interaction studies

At all steps for aerosols, clouds and cloud-aerosol Interaction, we will need the participation and collaboration of the modeling community. Our approach is to produce a well-characterized data set that *will constrain model predictions* of climate change.

Now we have a mostly qualitative picture of the Earth's global aerosol system, made quantitative through retrievals using assumptions that are difficult to verify.

With ACE, we progress to a quantitative characterization based on direct measurements and straightforward inversions.

Back up

	Science Questions	Geophysical Parameters	Measurement Requirements	Mission Requirements
SPTS	(1) What are the key sources, sinks and transport paths of airborne sulfate, organic, black carbon, sea salt and mineral dust aerosol? (2) What is the impact of specific significant aerosol events such as volcanic eruptions, wild fires, dust outbreaks, urban/industrial pollution etc. on the local, regional and global aerosol burden?	Column: - $\tau_a(\lambda)$ - $\tau_{a\text{-}abs}(\lambda)$ - $m_a(\lambda)$ (2 modes) - $r_{eff,a}$ (2 modes) - $v_{eff,a}$ (2 modes) -morphology Vertically resolved: -extinction - $\tau_{a\text{-}abs}(\lambda)$ - $m_a(\lambda)$ - $r_{eff,a}$ - $v_{eff,a}$ -morphology Cloud Top for (3) and (4) only: - τ_c - $r_{eff,c}$ - $v_{eff,c}$ - thermo-dynamic phase Definitions and accuracy requirements in Appendix	High Resolution Spectral Lidar (HSRL): -backscatter 355 nm, 532 nm, 1064 nm -extinction 355nm, 532 nm - backscatter 100m vertical 100m along track - depol in 2 channels Imaging polarimeter: -minimum 6 to 8 wavelengths spanning either UV or 410 nm to either 1630 nm or 2250 nm. - Multiangle TBD, range ±50° at spacecraft - polarization accuracy 0.5% - combination polarized and non-polarized channels possible - resolution 250 m in at least one channel -swath 2-day coverage for (1) and (2) -swath ~400 km for (3) and (4) Instrument designs must demonstrate attainment of Geophysical Parameter accuracies in Appendix Measurement requirement details in Appendix	Integrated satellite, sub-orbital and modeling approach required to meet science obectives. Required ancillary data: - land surface albedo map - ground network $\tau_a(\lambda)$, shortwave and longwave F_d and F_{net} - ground and airborne: column and vertically resolved $\tau_a(\lambda)$, $\tau_{a\text{-}abs}(\lambda)$, $m_a(\lambda)$ (2 modes), $r_{eff,a}$ (2 modes), $v_{eff,a}$ (2 modes), morphology, $P_{a\text{-}pol}(\Theta)$ - space measurements: Top of atmosphere shortwave and long wave F_u , collocated $T(z)$, $q(z)$, $V(z)$, fire strength, frequency and location orange for (1) or (2) only blue for (3) or (4) only black for both
DARF	(3)What is the direct aerosol radiative forcing (DARF) at the top-of-atmosphere, within-atmosphere and at the surface? (4) What is the aerosol radiative heating of the atmosphere due to absorbing aerosols, and how will this heating affect cloud development and precipitation processes?			

CAI

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<tr><th>Science Questions</th><th>Geophysical Parameters</th><th>Measurement Requirements</th></tr>
<tr><td>How much do anthropogenic additions to natural aerosol affect the planetary energy balance via their influence on droplet and crystal nucleation?</td><td rowspan="5"><u>Vertically resolved:</u>

1. N_a
2. $\tau_{a\text{-}abs}(\lambda)$
3. $r_{eff,a}$
4. N_c
5. cloud liquid water content
6. precipitation

<u>Cloud top</u>

7. cloud top height
8. Cloud albedo
9. Cloud liquid water path
10. τ_c
11. $r_{eff,c}$
12. cloud radiative effect

<u>Cloud base</u>

13. cloud base height
14. updraft velocity</td><td rowspan="5">High Resolution Spectral Lidar (HSRL): 1, 2, 3, 10

Imaging polarimeter: 1, 2, 3

W Band Radar: 4, 5, 6, 7, 13, 14

Ka Band Radar: 4, 5, 6, 7, 13

High-Resolution VIS-SWIR Imager: 7, 9, 10, 11, 12

Wide Swath Vis-IR Imager: 9, 11

Low Freq. Microwave: 5, 6, 9, 11

High Freq. Microwave: 5, 9, 11</td></tr>
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</table>

Science Questions → **Goals** → Approach → Parameter Requirements → Instrument Requirements

- Constrain total aerosol mass burden in atmosphere to ±4.5 Tg, which represents cutting present uncertainties in half. Constrain uncertainty in total AOD from 0.025 to less than 0.02, constrain Mass Extinction Efficiencies (MEE), individual species, sources, deposition.
- Represent PM2.5 concentrations on the ground from satellite observations with $R > 0.8$.
- Quantify hemispheric transport of pollution to ±50%, representing cutting uncertainties in half
- Quantify contribution of major aerosol events to total air quality burdens and regional and global aerosol radiative forcing.

- A firmer basis for measurement-based estimates of global and regional DARF and its uncertainties by confronting issues not properly addressed by observations in the past.
- The first ever measurement-based estimate of the global direct aerosol radiative forcing at the bottom of the atmosphere to within ± 1 Wm^{-2}, equivalent to estimating **the global evaporation rate at the surface of ± 1 mm/month** (~ 1% of global rates).
- Measurement-based estimates of the aerosol radiative heating of the atmosphere, vertically-resolved into layers, at an accuracy of ± 0.25 ^{o}K/day for 1.5 km layers.

Science Questions → Goals → Approach → **Parameter Requirements** → Instrument Requirements

For all surfaces, in the day time, 1 stdev within error bars,
Aerosol retrievals must be free of cloud artifacts:

(a) AOD (UV-VIS-SWIR) ±0.02 or 5% SPTS-1,2, DARF-3,4, IARF

(b) global mean *anthropogenic* AOD ± 0.008 1,3,4

(c) morphology (degree of nonsphericity),
column in cloud-free, above clouds in cloudy 1,3,4, IARF
and vertically resolved 1, IARF (goal)

(d) Absorption AOD (UV-VIS-SWIR) ±0.02 of the total AOD_VIS > 0.10,
column in cloud-free, above clouds in cloudy 1,3,4, IARF

(e) Real part of the refractive index (UV-VIS-SWIR), two particle modes
column integrated: 1,3,4, IARF; goal: vertically resolved 1, 4, IARF

(f) Size distribution, two particle modes.
Modal effective radius ±10%, effective variance ±50%.
column integrated 1, 3, 4, IARF goal vertically resolved 1,4, IARF

Science Questions → Goals → Approach → Parameter Requirements → Instrument Requirements

(g) Aerosol extinction to ±0.025 km^{-1}. 1 to 1.5 km layers FT. 500 m BL. 1,3,4, IARF

(h) Vertically resolved ω_o to within ±0.02; 1 to 1.5 km FT, 500 m BL DARF-4

(i) column particle number concentration (±100%) attributed to two size ranges corresponding to a coarse mode (roughly supermicron) and to an accumulation mode (roughly 0.10 µm to 1.0 µm). IARF

(j) vertically resolved particle number concentrations (± 100%); vertical resolutions of 500 m in boundary layer and 1.0 to 1.5 km in the free troposphere. IARF

(k) Cloud optical thickness (8%) cloud particle effective radius (10%), effective variance (±50%), and thermodynamic phase. 3,4, IARF

(l) 10 km spatial resolution along track and across image (product). 1,2,3,4, IARF
Goal: 500 m or less. 1,2, IARF

Science Questions → Goals → Approach → Parameter Requirements → Instrument Requirements

(m) 5 year mission; continuity with heritage data bases 1,2,3,4, IARF

(n) Global unbiased parameters, and regional/seasonal means. 3,4

(o) 2-day global coverage 1,2

(p) Assimilation model and integrated sub-orbital support essential.
1,2,3,4, IARF